Complete Oxidation of Benzene over $Au-V_2O_5/TiO_2$ and $Au-V_2O_5/ZrO_2$ Catalysts

D Andreeva, T Tabakova and V Idakiev

Institute of Catalysis, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria

and A Naydenov

Institute of General and Inorganic Chemistry, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria

A gold promotional effect is reported for the complete oxidation of benzene using Au/V_2O_5 supported on titania or zirconia catalysts.

The complete catalytic oxidation of hydrocarbons has received much attention in connection with enabling increased environmental protection from their emission from motor vehicles and processing plants. The many studies have involved the use of various metals, metal oxides and mixed metal-metal oxide systems as catalysts for these reactions (1-3).

This paper gives a short account of the high catalytic activity found for the complete oxidation of benzene using gold-promoted vanadium pentoxide catalysts supported on titania or zirconia. There are results described in the literature on the promoting effect of Pd and Ag over supported vanadium pentoxide (2, 3) related to the activation of oxygen, and the reversible oxidation of V^{4+}, thus leading to an equilibrium in the redox process. The promoting effect of gold in catalysts used for the complete oxidation of various saturated and unsaturated aliphatic hydrocarbons and other materials has already been reported (4); but the present results are the first to describe the effects of gold promotion on supported vanadium pentoxide catalysts for the complete oxidation of benzene.

Six catalyst samples were studied: *ie* Au/TiO_2, V_2O_5/TiO_2, $Au/V_2O_5/TiO_2$, Au/ZrO_2, V_2O_5/ZrO_2, and $Au/V_2O_5/ZrO_2$. The samples were prepared by deposition-precipitation of gold onto the support and impregnation with $(NH_4)_2[VO(C_2H_4)_2]$. The precursors were dried under vacuum and calcined at 400°C for 2 h, the atomic $Au:V_2O_5:MO_2$ (M = Ti, Zr) ratios being 1 : 1.3 : 31. The average particle size of the supported gold clusters was 2 - 3 nm for those on titania and 3 - 4 nm for those on zirconia, as determined by X-ray diffraction (XRD) and transmission electron microscopy (TEM).

The catalytic activities of the samples were evaluated in a gradientless reactor with external circulation under the following conditions: catalyst volume - 0.2 cm^3 (particle size 0.25 - 0.50 mm), inlet benzene concentration - 0.019 mol m^{-3} in oxygen, temperature range 150 - 400°C. Figure 1 illustrates the catalytic activities obtained at 225°C expressed as moles of benzene oxidized per m^2 of the surface per second (mol m^{-2} s^{-1}).

The activities observed demonstrate that there is a synergistic effect giving increased activity in the catalysts when a combination of gold with vanadium oxide is present on both of the oxide supports employed. The increased benzene conversion effect occurs at about 150°C lower than was found previously for promotion of vanadium oxide catalysts by palladium or silver where the 90 - 95% conversion is reached at 400°C (2, 3). At 250°C, the conversion of benzene on $Au/V_2O_5/TiO_2$ is 98%, compared with 50% for V_2O_5/TiO_2; and for $Au/V_2O_5/ZrO_2$ 70% compared with 30% for V_2O_5/ZrO_2.

The unusual properties of the gold nanoclusters thus cause a considerable enhancement of the catalytic activity of the supported vanadium oxide for the complete oxidation of benzene. There are data on the formation of low coverage hydroxy species on gold established by optical and electrochemical measurements (5 - 7). Such surface gold atoms with low coordination numbers are more energy-rich and

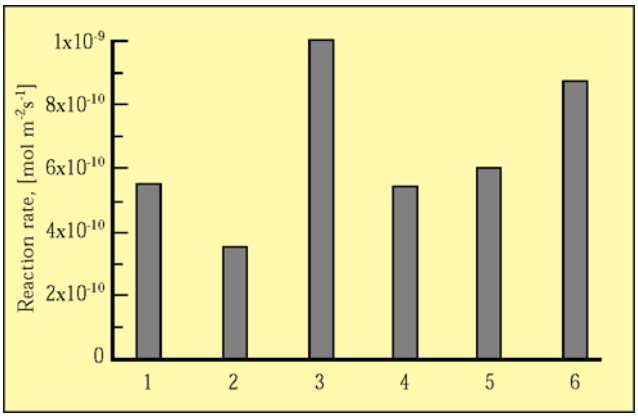

Figure 1 *Rates for the complete oxidation of benzene at 225°C for the catalyst samples: 1 V_2O_5/TiO_2, 2 Au/TiO_2, 3 $Au\text{-}V_2O_5/TiO_2$, 4 V_2O_5/ZrO_2, 5 Au/ZrO_2, 6 $Au\text{-}V_2O_5/ZrO_2$.*

unusually reactive. Upon oxidation or contact with water these atoms can coordinate more oxygen or hydroxide species and are able to participate actively in redox reactions on the surface. It could be suggested that the activation of oxygen takes place on the finely divided gold particles on the surface while the benzene is adsorbed on vanadium oxide, via a similar mechanism to that proposed by Andreev *et al* (2, 3) for the complete oxidation of benzene on $Pd/V_2O_5/Al_2O_3$ and $Ag/V_2O_5/Al_2O_3$.

REFERENCES

1 D.L. Trimm, *Catal. Rev.*, 1977, **16**, 155
2 M. Vassileva, A. Andreev, S. Dancheva and N. Kotsev, *Appl. Catal.*, 1989, **49**, 125
3 M. Vassileva. A. Andreev and S. Dancheva, *Appl. Catal.*, 1991, **69**, 221
4 M. Haruta, *Catalysis Surveys of Japan*, 1997, **1**, 61
5 L.D. Burke, *Electrochim. Acta*, 1994, **39**, 1841
6 L.D. Burke, *Platinum Metals Rev.*, 1994, **38**, 166
7 L.D. Burke, *Gold Bull.*, 1998, **31**, 39

BOOK REVIEWS

The Gold Explorer's Handbook

by James Regan, Published by Rosendale Press (London, UK) 1997, 224 pages, ISBN 1 872803 32 6, Price £25.00

In his foreword, James Regan gives his personal view of gold exploration, which he describes as a colourful and exciting part of human history. The language style in the foreword and elsewhere reflects the fact that James is the son of a professional soldier. The practical details provided throughout the chapters provide ample evidence that he has a valuable working knowledge gained from over thirty years working at the 'front line' of gold exploration in various parts of the world from Australia to Zimbabwe. He is full of praise for field workers and scientists working in gold exploration and emphasizes the importance of teamwork, careful planning, attention to detail and the value of local knowledge for trouble-free expeditions.

What makes this book a good read as well as a valuable handbook, is the nice combination of real occurrences and stories with thorough, stepwise and practical guidelines to gold exploration provided in the individual chapters. It is written with enthusiasm and style. Since first receiving this book for review some time ago, I have undertaken my own first guided 'expedition' down an abandoned gold mine in Wales and again experienced first-hand the excitement of panning for gold !

The book is divided into two parts, both well presented, with helpful checklists and tables included throughout. In Part 1 (chapters one to seven), important practical guidelines are presented, with Part 2 focusing on more specialist techniques from chapters eight to ten. Where appropriate, useful literature and book sources for further reading are given at the bottom of the individual pages. Valuable appendices on the properties of gold, a glossary of scientific terms, a bibliography and up-to-date details on key suppliers, and information sources including computer software and web sites are provided at the back of the book. In Chapter 1, the author describes the first steps in the exploration for gold, discussing in particular the budget, potential difficulties with exploration licences, political factors, gaining the co-operation and respecting the customs of the local community, and environmental protection. The required traits of an explorer are emphasized, in such lines as "anyone…who cannot exist without a regular newspaper, hot bath and an air-conditioned room plus liberal